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Non-Invasive and Micro-Invasive Analyses for Supporting the Attribution of Three 17th Century Wooden Crucifixes: Pictorial Materials and Construction Techniques of *Fra' Umile da Petralia*

Maria Francesca Alberghina [1], Salvatore Schiavone [1,*], Antonio Alaimo [2], Enza Gulino [2], Giuseppe Mantella [3], Luciana Randazzo [4,5], Michela Ricca [6], Valeria Comite [7,*], Silvestro Antonio Ruffolo [6] and Mauro Francesco La Russa [6]

1. S.T.Art-Test di S. Schiavone & C Sas, Via Stovigliai 88, 93015 Niscemi, Italy; francesca.alberghina@gmail.com
2. Alaimo e Gulino Conservazione e Restauro, via Trinità, 2/A, 90024 Gangi, Italy; alaimogulino@libero.it (A.A.); alaimogulino@gmail.com (E.G.)
3. Giuseppe Mantella Restauro Opere D'ARTE, Via Circonvallazione Paparo 25, 88060 Isca sullo Ionio, Italy; mantellag@yahoo.it
4. Department of Earth and Marine Sciences (DiSTeM), University of Palermo, Via Archirafi 26, 90123 Palermo, Italy; luciana.randazzo@unipa.it
5. Istituto Nazionale di Geofisica e Vulcanologia (INGV), 90146 Palermo, Italy
6. Department of Biology, Ecology and Earth Sciences (DiBEST), University of Calabria, Ponte P. Bucci, Cubo 12b, 87036 II Piano, Italy; michela.ricca@unical.it (M.R.); silvestro.ruffolo@unical.it (S.A.R.); mauro.larussa@unical.it (M.F.L.R.)
7. Dipartimento di Chimica, Università Degli Studi di Milano, Via Golgi 19, 20133 Milano, Italy

* Correspondence: info@start-test.it (S.S.); valeria.comite@unimi.it (V.C.)

Abstract

This research deals with a multi-analytical approach to characterise three polychrome wooden crucifixes attributed to *Fra' Umile da Petralia* or, in one case, close to his style. The analysed wooden sculptures belong to (1) the Sanctuary of Saint Umile from Bisignano (Cosenza, Italy); (2) the Santissimo Crocifisso Church at Cutro (Crotone, Italy); (3) the Saint Salvatore Church at Gangi (Palermo, Italy). *Fra' Umile* (Giovanni Francesco Pintorno) was born in Petralia Soprana (Palermo, Sicily) between 1600 and 1601, died on 9 February 1639, and belonged to the Order of Friars Minor. Systematic research of the materials and constructive techniques of wooden sculptures is still not very wide, although diagnostic analyses could represent a useful tool for art historians and restorers for these typologies of works of art. The wooden sculptures were subjected to both non-invasive and micro-invasive investigations. Digital direct X-ray radiography, SEM-EDX, and X-ray fluorescence analyses have been carried out, revealing for the three analysed sculptures a similar construction technique and similar pictorial materials. The provided diagnostic evidence supports the coincident chronology and the same attribution to *Fra' Umile da Petralia* or his workshop, confirming the proposals based on the stylistic comparative analyses and archival historical documents. The results of this first multi-analytical investigation, documenting the artistic technique and construction system, represent a starting point for future systematic study on the artistic production of this prolific artist and sculptor never studied from a technical–scientific point of view to date.

Keywords: multi-analytical investigation; digital radiography; wooden sculptures

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1. Introduction

Fra' Umile da Petralia, born Giovanni Francesco Pintorno, was a Sicilian sculptor who left an indelible mark on the Baroque period through his religious artwork. Originating from the small town of Petralia Soprana (Palermo, Sicily) around 1600, his life and artistic production were profoundly shaped by his commitment to the Franciscan Order [1–3]. Very little is known about his early life, but it is assumed that he grew up surrounded by the artisanal traditions of his region, which likely increased his interest in sculpture. At a young age, he joined the Franciscan convent and adopted the name "*Umile*", meaning "humble", a reflection of his spiritual devotion. His sculptures, particularly his wooden crucifixes, were deeply influenced by the Franciscan ideals of simplicity, humbleness, and direct religious experience [2]. His artistic production is known for its emotional depth and naturalism, characteristics that align with the broader themes of the Baroque style, which aimed to evoke strong emotional responses, particularly in religious art. The sculptures attributed to *Fra' Umile da Petralia* often depict Christ in moments of extreme suffering, capturing the raw agony of the Passion with meticulous anatomical detail. The naturalism in his representations of Christ on the cross, showing strained muscles, visible ribs, and pained facial expressions, was designed to inspire viewers to contemplate the suffering of Christ on a personal level [1,2]. His artworks can be found in several churches and convents in Sicily and Southern Italy, indicating his widespread influence during his lifetime.

A systematic search of the pictorial materials and construction techniques of these artworks has rarely been conducted in the scientific community. However, there has been growing interest in the last decade, and several studies describe wooden materials and their distribution in different geographical areas [4–8]. A detailed study of the polychromies wooden statues dated in the 16th and 17th century would allow the correct identification and differentiation of the workshops and active artists and consequently a scientific attribution in addition to that based on artistic–stylistic criteria. This traditional approach is often influenced by the difficult reading of the original models and surfaces altered by the frequent pictorial overlays and remakes to which these wooden sculptures have generally been subjected, due to their continuity of use for religious devotion. These limits can be overcome by systematic radiographic investigation. Diagnostic analysis, referring to both non-invasive and micro-destructive techniques, could unveil information about the materials and the execution techniques [9–15]. In this research, three wooden sculptures attributed to *Fra' Umile da Petralia* were the object of a multi-analytical investigation, coming respectively from (1) the Sanctuary of Saint Umile from Bisignano (Cosenza, Calabria), (2) the Santissimo Crocifisso Church at Cutro (Crotone), and (3) the Saint Salvatore Church at Gangi (Palermo).

The three sculptures investigated were analysed according to a multi-analytical approach based on integrated non-invasive techniques (digital X-ray radiography, UV fluorescence imaging, and portable X-ray fluorescence spectrometry) to understand the state of conservation, to document the construction system and the number of pieces assembled to obtain the whole volume, and to identify the original painting materials. In two cases (Bisignano and Cutro crucifixes), it was possible to deepen the study of the pictorial materials, through scanning electron microscopy analysis and microprobe analysis (SEM-EDS) for the compositional characterisation and stratigraphic study of the pictorial and preparation layers.

Iconographic Study and Stylistic Analysis of the Investigated Wooden Crucifixes

The Crucified Christ from the Sanctuary of *Sant'Umile da Bisignano* at Bisignano (Cosenza, Calabria) (Figure 1a) is attributed to *Fra' Umile da Petralia* and dates back to the 17th century. On the back of the wooden cross, the following inscription is engraved: "1637. P.F. GREGORIO A BISIN. CUSTOD F. HUMILIS A PETRALIA REFOR. SCULP".

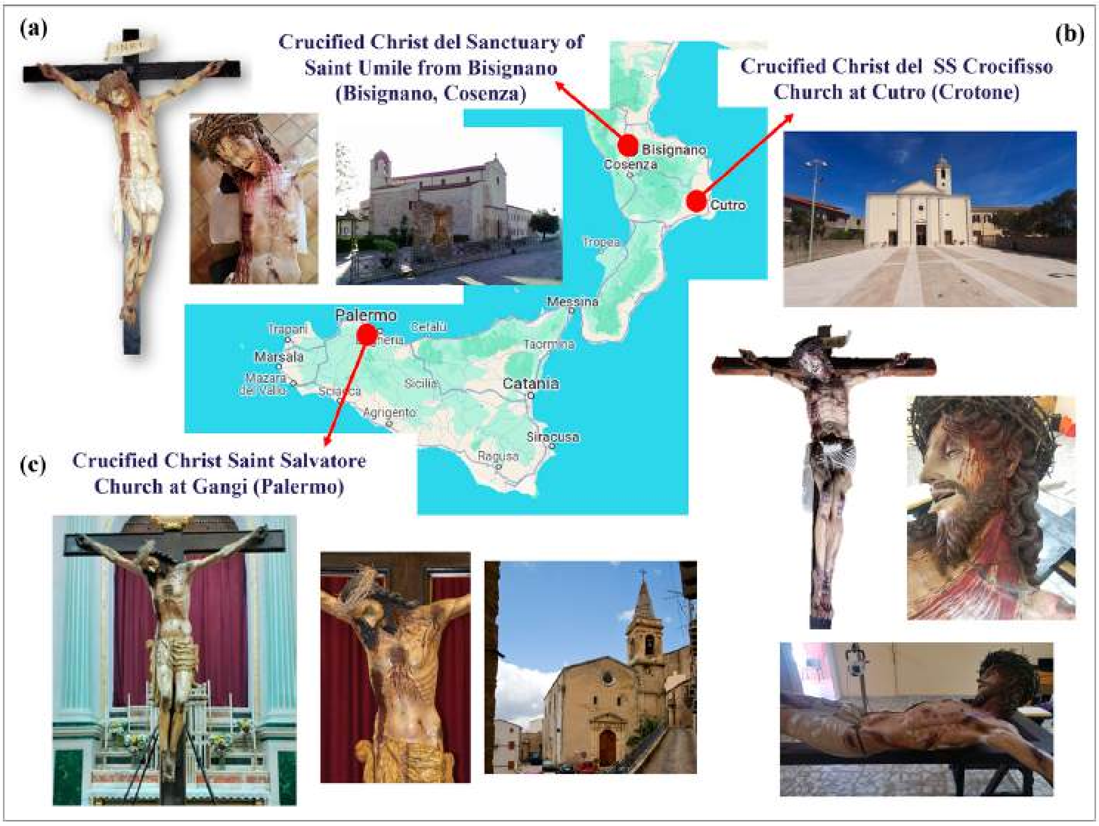


Figure 1. Geographic location of the three analysed polychrome wooden sculptures: (**a**) Crucified Christ, Sanctuary of *Sant'Umile da Bisignano* at Bisignano (Cosenza, Calabria), with a detail of the torso and face; (**b**) Crucified Christ, *Santissimo Crocifisso* Church at Cutro (Crotone, Calabria), with a detail of the face and torso; (**c**) Crucified Christ, *Saint Salvatore* Church at Gangi (Palermo, Sicily), with a detail of the torso and face.

The Crucified Christ from *Santissimo Crocifisso* Church at Cutro (Crotone, Calabria) (Figure 1b) is also traditionally attributed to the sphere of *Fra' Umile* [3]. The Jesuit biographer P.G. Macaluso [1,2] places the creation of the Crucified Christ of Cutro between 1636 and 1637, simultaneously with the Crucifixes from Bisignano and the Crucifixes from Polla (Salerno, Campania), with which it shares several details. However, it is distinguished from these and other wooden crucifixes attributed to the same workshop by the presence of a fine artistic detail, a tear falling from the left eye and suspended on the tip of the nose (see detail of the face, Figure 1b).

The Crucified Christ in the Saint Salvatore Church at Gangi (Palermo, Sicily) (Figure 1c) dates back to between the 16th and 17th centuries. This artwork bears no inscriptions, but its stylistic characteristics lead to its attribution to *Fra' Umile da Petralia.* Oral tradition over the centuries reports this as a unique attribution; although no document has ever confirmed this hypothesis, several stylistic elements refer to the style of Giovanni Pintorno or his workshop [3]. Furthermore, the discovery of a document dated in 1656 testifies to the remaking of the pictorial layers by the monks of the nearby town Petralia Sottana (Palermo), custodians and successors of the Franciscan art typical of *Fra Umile da Petralia*. This archival source belongs to the "Accounting book of the Church of the Saint Salvatore from 1646 to 1691" preserved at the Mother Church of Gangi. In fact, in 1656 a payment of "14 *onze*" to the monks is recorded for repainting the wooden sculpture of the SS. Crucifix.

This document therefore demonstrates that the Crucifix was created before 1656, probably according to a style based on naturalism and strong emotional impact spread by *Fra' Umile*, and on that occasion, it was stylistically adapted to the artistic and cultural taste of that time. It is clear that almost twenty years after his death (1639), his realistic and emotional style carried on by the workshop was widespread and preferred by religious commissions.

2. Materials and Methods

The pictorial compositional and stratigraphic characterisation and construction technique study of the polychrome wooden sculptures was carried out with a multi-analytical approach, using both non-invasive and micro-invasive methods. The latter were applied only to two of the crucifixes, the one from the Church of the Santissimo Crocifisso Church at Cutro and the one from the Sanctuary of Saint Umile from Bisignano. The micro-sampling was not authorised for the third crucifix, from the Saint Salvatore Church in Gangi (Palermo). For the latter, only non-invasive elemental analyses were carried out by p-XRF investigation. The study aimed to characterise the artistic technique and the artist's modus operandi in the production of these polychrome wooden sculptures, to attribute or validate the attribution to *Fra' Umile da Petralia*, and to use the information obtained for future comparisons with other artworks attributed to the same artist or his workshop. In addition, studies were carried out to characterise the original layers of the pictorial layers, which provide essential information for restorers during the conservation phases. Finally, considering the minimum number of samples that could be taken, preliminary information was obtained for the identification of the wooden species used for the related part of the statues.

2.1. Micro-Fragment Sampling from the Pictorial Surface

From the Crucifix of the Santissimo Crocifisso Church in Cutro, three micro-fragments were taken from the pictorial layer on both the front and back of the Crucifix, along with an additional sample for wooden species identification.

Moreover, three micro-fragments were taken from the Crucifix of the Sanctuary of *Sant'Umile da Bisignano*: two samples were for the pictorial layer analyses, and one sample was for the preliminary identification of the wood species. Figures 2 and 3 localise and describe the samples from these two analysed polychrome sculptures.

(**a**) CC_01 (**b**) CC_02 (**c**) CC_03 (**d**) CC_04

Figure 2. List of micro-fragments sampled from the Crucified Christ at Cutro: (**a**) CC_01, from flesh tone pictorial layer from the back of the Christ (left side); (**b**) CC_02 from flesh tone pictorial layer from the spinal column; (**c**) CC_03 from dark red pictorial layer from dripping blood; (**d**) CC_04, wood fragment from a lacuna on the top of head.

(**a**) CB_01 (**b**) CB_02 (**c**) CB_03

Figure 3. List of micro-fragments sampled from the Crucified Christ at Sanctuary of *Sant'Umile da Bisignano*: (**a**) CB_01, from flesh tone pictorial layer, taken along a fracture between the shoulder and the arm (left side); (**b**) CB_02, micro-fragment of paint layer (dark red) from the rib cage of the Christ at the site of blood (left side); (**c**) CB_03, wooden micro-fragment from a fracture at the back of the Christ's head.

2.2. Non-Invasive Methodologies

A portable direct digital X-ray radiography system was employed to understand the construction techniques of the three crucifixes. This diagnostic technique allows for the non-invasive analysis of the internal structures of artworks by studying the material discontinuities along the whole involved volume based on their radiopacity. This powerful investigation method provides information on the conservation state, detecting lacunae, fractures, defects, entomological attached evidence, and indications of the construction technique [16]. The portable X-ray system used for this study consists of a portable X-ray tube Poskom X+ (Northbrook, IL, USA), model PXP-100 CA, voltage from 40 to 100 kV equipped with a positioning system and an optical aiming system; a direct digital detection system: the AGFA DR 14e digital radiography plate, which consists of an amorphous silicon TFT detector, with a pixel pitch of 150 µm, active matrix 2336 $\times$ 2836 pixels with an active area of 430 mm $\times$ 350 mm, 16-bit images, and a minimum spatial resolution 3.36 lp/mm.

A preliminary cover meter survey was carried out, which aimed to correctly plan the in-situ RX acquisition and to optimise the projection of different X-ray expositions. This method allows a fast localisation of metallic structures within the wooden volume of the sculptures, measuring the absorption of the magnetic field generated by the same equipment. The metallic inserts are identified by slowly moving the probe over sensitive areas to locate the points and directions of maximum signal. The cover meter system used is the Profoscope+ by Proceq (Screening Eagle Technologies, Schwerzenbach, Switzerland).

Ultraviolet-induced visible fluorescence investigation allows for the observation and acquisition of high-resolution images of optical fluorescence stimulated by ultraviolet illumination, for the non-invasive and immediate detection of original materials and restoration materials constituting the analysed artistic surface [17–22]. The analysis also allows for the assessment of the conservation state and ageing of the protective paint, as well as the monitoring of restoration phases, for example, verifying the removal of altered paint layers. For acquisitions in optical fluorescence stimulated by UV radiation, a CCD photosensor (multispectral system Samsung NX500 28.2 MP, customised by Madatec srl, Monza, Italy) was used, equipped with a UV-IR filter to allow the detector to only reach the visible fluorescence radiation emitted by the examined materials. Visible fluorescence is induced by ultraviolet light sources (two LED sources filtered with an emission peak centred at 365 nm, positioned at 45 degrees to the observed surface).

X-ray fluorescence spectrometry (XRF) is a non-invasive analysis that allows the identification of chemical elements present in the surface materials, performed using a portable spectrometer [16,23]. In this study, this analytical technique was employed on the polychrome statue of the Crucified Christ from the Saint Salvatore Church at Gangi (Palermo), for which no sampling was conducted for the characterisation of the pictorial layers. The portable XRF spectrometer (Amptek Inc. Bedford, MA, USA) used for the multi-elemental analysis of pigments consists of an X-ray tube (Mini-X-Amptek, Amptek Inc. Bedford, MA, USA) equipped with a Rhodium (Rh) target, operating at a maximum working voltage of 40 kV and maximum current of 0.2 mA. Detection of the characteristic X-ray radiation emitted by the sample is energy-dependent (Energy Dispersive: ED-XRF) and enabled by a Silicon Drift Detector system (X-123 SDD—Amptek) with 125–140 eV FWHM at 5.9 keV Mn Kα line energy resolution (depending on the peak time and temperature), and a collimator of 1 or 2 mm. The energy detection range is from 1 keV to 40 keV, with a maximum counting rate of up to 5.6×10^5 cps. The primary beam is positioned perpendicular to the sample, while the detector is positioned at 40 degrees relative to the primary beam. Dedicated control software allows for the evaluation of measurements and acquisitions. For the analysis of the 9 selected areas, the following measurement parameters were set to ensure a good spectral signal and optimise the signal-to-noise ratio (SNR): voltage 35 kV, current 80 μA, acquisition time 50 s per area, working distance 1 cm.

Scanning electron microscopy coupled with energy dispersive X-ray analysis (SEM-EDS) was used for the morphological observation of the micro-samples collected and to perform microanalysis in terms of the elemental composition [24]. For this purpose, a Zeiss Crossbeam 350 microscope (Carl Zeiss SMT, Oberkochen, Germany), equipped with an Energy Dispersive Spectrometer (EDS), was used.

3. Results

3.1. Crucified Christ from Santissimo Crocifisso Church at Cutro (Crotone)

A preliminary cover meter survey revealed metallic elements only in the area between the head and the neck, corresponding to a junction line, observable at close vision (Figure 4). No other joints and nails were revealed in the remaining volume of the statue.

Figure 4. Preliminary survey by cover meter on the Crucified Christ of Cutro aimed to detect metal pins/nails corresponding to a junction line. The red laser indicates the exact coincidence between the sensor and the metallic elements present in the volume.

This information supported the design of successive radiographic in situ investigation in terms of the number of exposures for the area to obtain information on the direction and extension of these metal internal elements used for assembling the wooden pieces.

In situ radiographic investigations were carried out on the entire volume of the statue in an antero-posterior projection. Moreover, portions of the head, right hand, and feet were also acquired in latero-lateral or 45° oblique projection for a detailed understanding of the state of conservation in the case of the foot and hand and a more complete relief of the position and orientation of the metal anchoring pins, in the case of the head (Figure 5), starting from the information provided by the preliminary cover meter survey. Thanks to the processing and interpretation of the radiographic images, it was possible to deduce the following information for each investigated area.

(a) (b) (c) (d)

Figure 5. X-ray images of the Christ Crucified of Cutro and comparison with photographic images: head, upper part of torso, and right shoulder acquired on a (**a**,**c**) 45° oblique projection and an (**b**,**d**) antero-posterior projection. At the end of the nose, more visible in the oblique projection, a thin metal wire supports the tear probably made of wax or other natural resin.

Concerning the head, torso, and shoulders (Figure 5a,b), the different projections carried out to understand the anchorage to the main stem showed the shape and direction of the four long nails documented at the base of the nape.

This allowed the unevenness of the surface at the back of the hair to be correctly interpreted as the areas of insertion of the metallic nails.

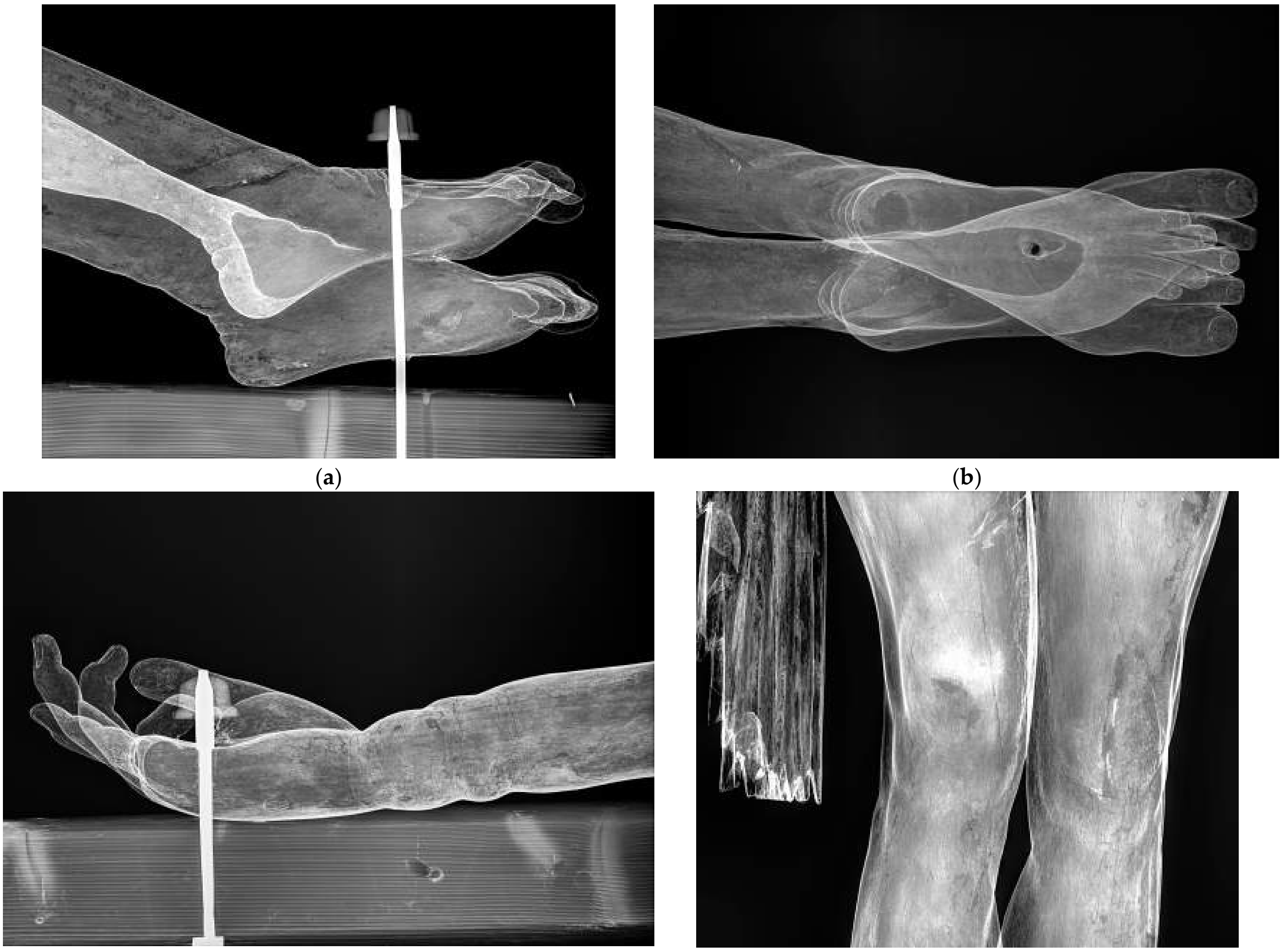
At the tip of the nose, a thin inserted metal wire can be seen to create a support for the applied material, forming the volume of a tear (Figure 5a). Other small metal nails were used to fix the crown of thorns on Christ's head (Figure 5a). There are no metal elements at shoulder height, but the joints between the arms and the main stem composed of tenons and wooden dowels are clearly visible. The direction of the tenon fibres, in continuity with those of the arm, is perpendicular to that of the fibres of the main stem on which it is fixed. The dimensions of the housing (mortise) are larger than those of the tenons. Between the left shoulder and the neck there is a radiopaque area, probably related to an integration area to fill a gap in the volume of the wooden stem (Figure 5b). Along the joints, irregular areas of lower radiopacity (darker areas) can be observed, which can be correlated to pictorial lacunae of the original layering. The contour lines of the different wooden pieces constituting the head and neck, which are anchored to the main stem are partially distinguishable. Moreover, two wooden dowels inserted into the chest, carved at one end to form nipples have been also documented (Figure 5b). On the abdomen and loincloth, the extension of the rectangular carving on which the spine is collocated and the presence of two little nails probably inserted to anchor it to the base have been documented (Figure 6a). The blood gushing from the Christ's side is characterised by high radiopacity, suggesting the presence of a high atomic number chemical element, a constituent of pigment in mixture (e.g., lead, mercury, etc.). At the loincloth (Figure 6b), it is possible to follow the outline of the irregularly shaped dowel applied on the back and the lacunae in the pictorial layer along the joint.

(**a**) (**b**)

Figure 6. X-ray images of the Christ Crucified of Cutro: (**a**) torso and (**b**) loincloth exposed by antero-posterior projection.

On the left side, there is a small nail that probably attaches the dowel to the main stem. Radiographic examination confirms that the loincloth was also obtained from the carving of the single trunk that makes up the body, as no joint lines, superficial fractures, metal anchors, or nails were observed in the analysed volume (Figure 6b).

The observations made on the arms–hands and legs–feet show no fractures, metal nails, or joint lines between the parts (Figure 7). This evidence confirms that the arms–hands system is carved from a single wooden piece, hooked at shoulder height. The blood drops on both hands and feet are radiolucent, suggesting a different mixture from the blood drops on the right side of torso. In general, there is little evidence of damage caused by xylophagous insects and limited lacunae and/or abrasion of the original pictorial layers, confirming the good state of conservation of the wooden support and painted surface.



(**a**) (**b**) (**c**) (**d**)

Figure 7. X-ray images of the Christ Crucified of Cutro: (**a**,**b**) feet, (**c**) right hand, and (**d**) legs exposed by lateral (**a**,**c**) or antero-posterior projection (**b**), after modern nail removal, and (**d**).

SEM-EDS analyses performed on micro-fragments taken from the original surface of both the front and back of the Crucified Christ allowed the identification of historical pigments, excluding modern pigments due to previous restorations, localised thank to the preliminary UV fluorescence observations.

The following pigments were identified on the flesh tone layers and blood drips at the level of the rib cage: lead white (white lead carbonate, $(PbCO_3)_2{\cdot}Pb(OH)_2$) [25,26], cinnabar/vermilion (HgS) [27], red lead (Pb_3O_4) or litharge (PbO) [26–28], and iron oxide based (ochres and earth pigments) [29]. In all the analysed samples, the presence of high sulphur and calcium contents was verified, attributable to calcium sulphate (gypsum), which can be attributed to the preparation layer.

The SEM-EDS spectrum acquired on CC_01 and CC_02 samples from the flesh tone layer show the presence of a first pictorial constituted by lead white and a low amount of clay mineral-based pigments (Figure 8). The overlapped dark red layer reveals the use of cinnabar/vermilion (HgS) (Figure 9). Moreover, the presence of additional chromophore elements, such as red lead or litharge, is not excluded; the latter may have also been used as a drier for protective varnishes [30]. Finally, the EDS analysis on internal layer confirms the identification of calcium sulphate as a constituent of the preparation layer (Figure 10).

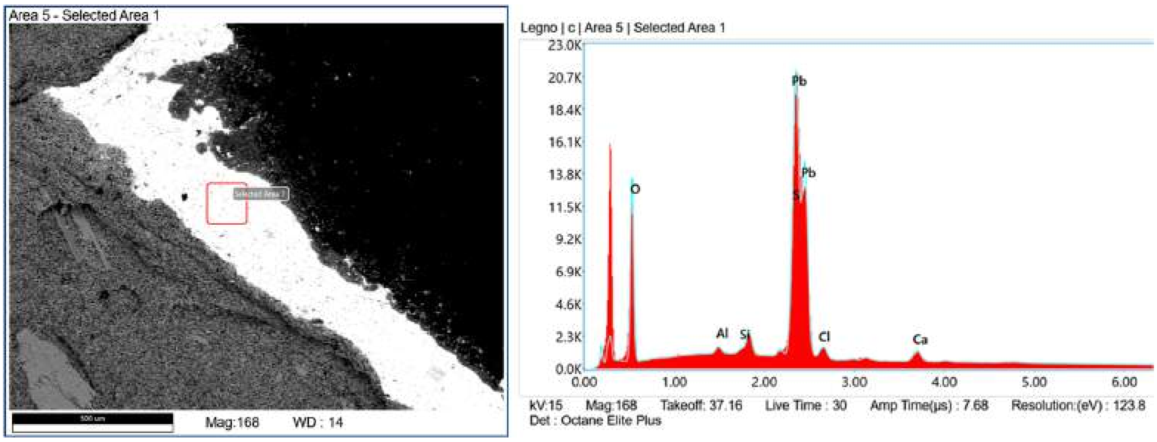


Figure 8. Christ Crucified of Cutro: SEM-EDS analyses on flesh tone pictorial layer of CC_01 sample.

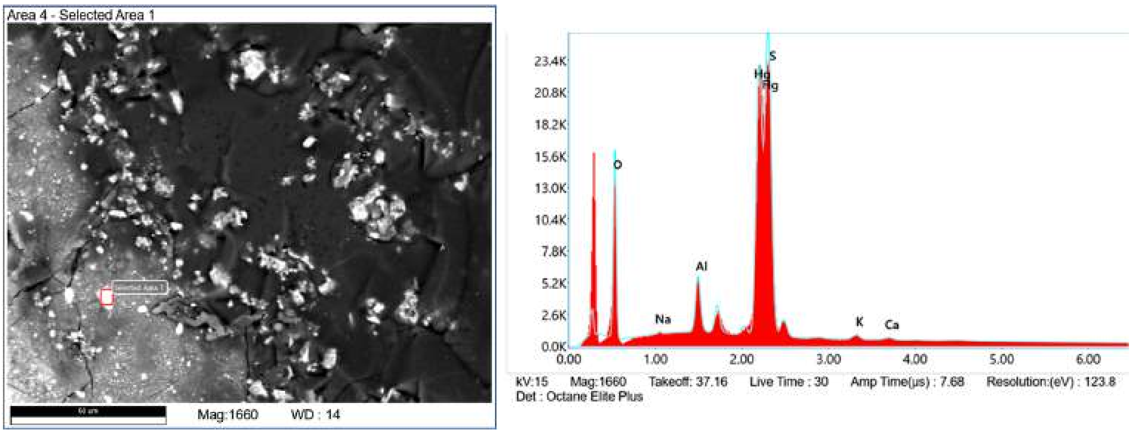


Figure 9. Christ Crucified of Cutro: SEM-EDS analyses on surface dark red pictorial layer of CC_01 sample.

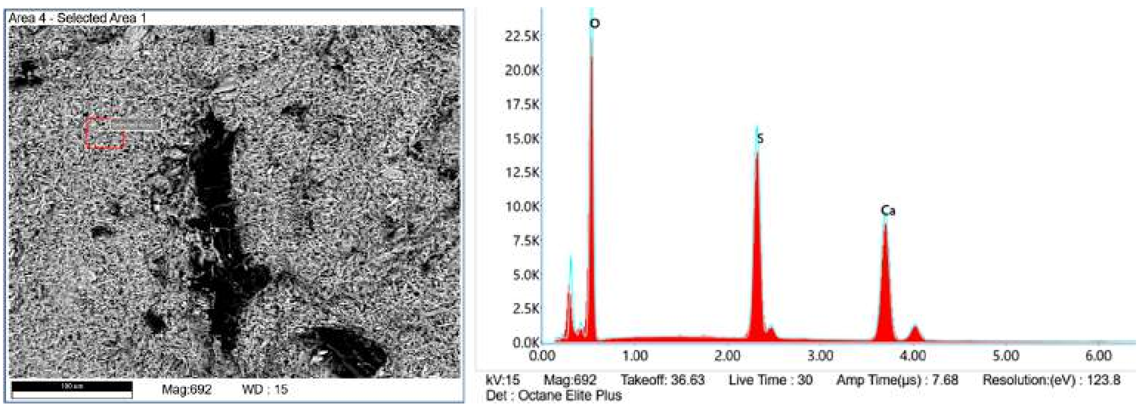


Figure 10. Christ Crucified of Cutro: SEM-EDS analyses on preparation layer of CC_01 sample.

Sample CC_03 (Figure 11), a micro-fragment from the drip of blood radiopaque in RX image, shows the presence of Hg and S, suggesting the use of cinnabar/vermilion, mixed with a lead-based pigment. Traces of phosphorus could indicate the use of an organic matrix for thickness applied to make the volume of blood drops. The presence of lead could be related to litharge (lead oxide) added as siccative [30]. Furthermore, the presence of aluminium, magnesium, and potassium suggest the use of mordants for the red lake, in a mixture to obtain the dark intense colour tone [31].

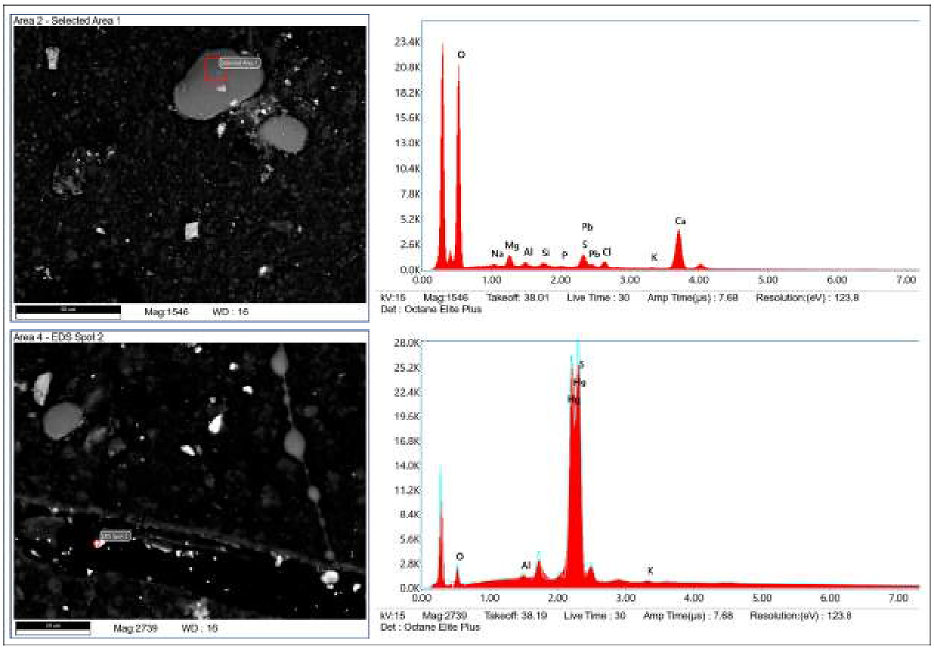


Figure 11. Christ Crucified of Cutro: SEM-EDS analyses on CC_03 sample from thick blood layer.

For the identification of the wood species, sample CC_04 taken from the top of the head was analysed by SEM-EDS (Figure 12). The SEM images showed the presence of a surface homogeneous layer that, from the EDS analysis, related to calcium sulphate constituting the preparation layer [32]. The morphological evidence provided by SEM observations of the wooden fragment suggests the use of poplar (*Populus*).

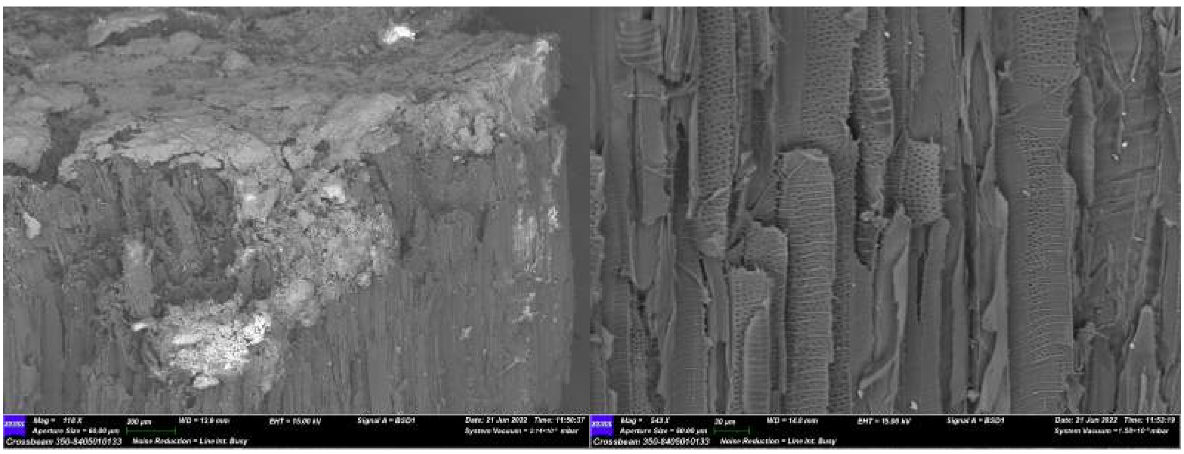


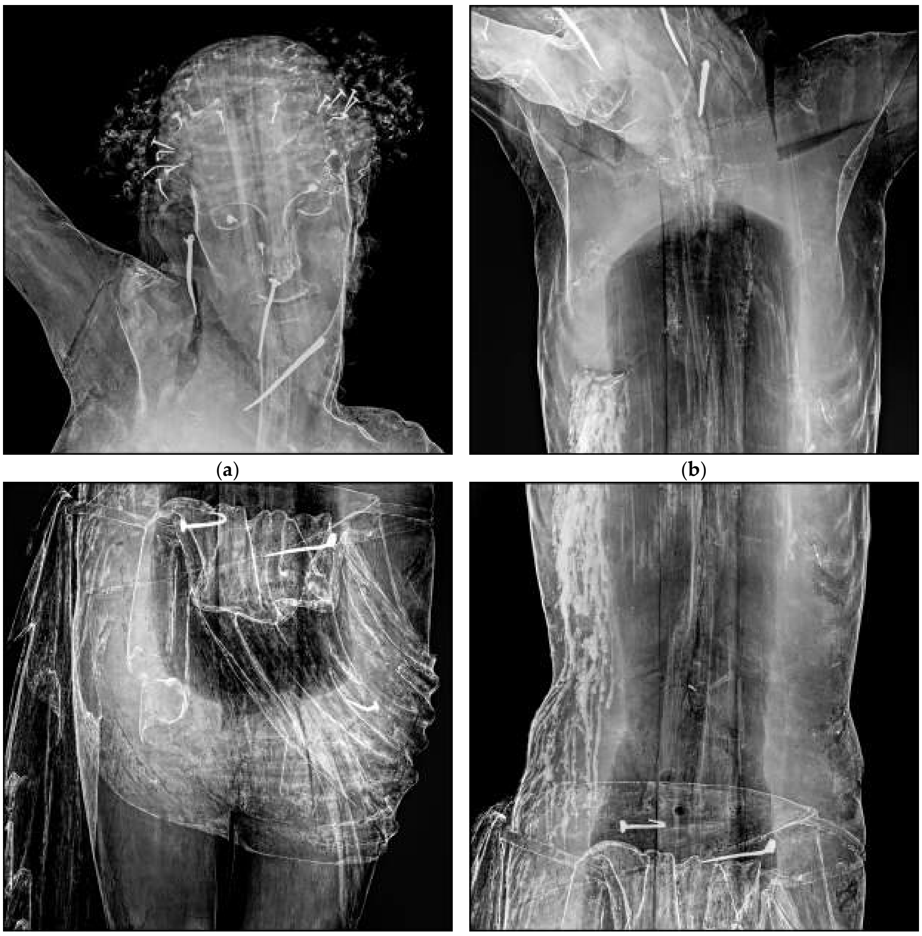
Figure 12. Christ Crucified of Cutro: SEM images of CC_04 wooden sample and preparation layer.

The genus Populus does not allow the precise identification of different species belonging to the group. The technological features of the wood are of three more diffused and similar species (*P. alba*, *P. nigra*, *P. tremula*), and there is a lack of knowledge of the correct species [4–6]. However, no information on the wood used for the body of Christ (which, as observed in the X-ray, appears to consist of a single central stem to which the head and arms were anchored) was obtained, due to the inability for further sampling.

3.2. *Crucified Christ, Sanctuary of Sant'Umile at Bisignano (Cosenza, Calabria)*

In this case, the preliminary cover meter survey also revealed metallic elements in the area between the head and neck and at the end of the torso. The low radiopacity of the pictorial and preparation layers allowed documentation of the features of the wooden volume of the whole sculpture, analysed by antero-posterior projection. In addition, portions of the head and neck were also acquired by latero-lateral and oblique 45° projection for a more complete understanding of the dimension and orientation of the nails already localised by the first cover meter survey.

The radiography images of the head and the upper part of torso (Figure 13) revealed the shape and direction of the three nails documented at the base of the nape of the neck; moreover, small nails applied to the head used to fix the crown of thorns were also documented. At shoulder height, there are no nails or metallic elements, but the assembly of the arms to the main stem by means of tenons and pegs (or thorns) is clearly visible. In the central part of the torso, the perimeter of the hollow rectangular carving is documented (Figure 13b). The absence of pictorial layers on the inner surface of the carving and the reduced thickness of the pictorial layer make the course of the fibres of the wooden stem used to carve the body legible.



(a) (b) (c) (d)

Figure 13. X-ray images of Christ Crucified from Bisignano: (**a**) head and part of the right shoulder (45° oblique projection); (**b**) neck and chest; (**c**) loincloth and part of legs; (**d**) abdomen and upper portion of the loincloth (antero-posterior projection).

The direction of the fibres of the head suggests that the piece of wood used comes from the same trunk, this one carved and shaped to obtain the desired inclination. The head and the rest of the main trunk return the same level of radiopacity, and we note the greater density of fibres in continuity in the central part of the two assembled parts (Figure 13a,b). There is also evidence of two wooden thorns inserted into the chest and carved at one end forming nipples, very similar to those documented in the Crucified Christ of Cutro. The blood flowing from Christ's chest (Figure 13c) is characterised by high radiopacity, suggesting the use of one or more pigments with a high atomic number such as Pb or Hg. At the end of the torso (Figure 13c,d), the X-ray images show the presence of two nails probably inserted to anchor a rectangular wooden element, applied to close the cavity carved on the back of trunk.

The loincloth (Figure 13d), as well as the legs and feet (Figure 14a,b) appear to have been carved from a single trunk constituting the body: neither joint lines, anchors, nor nails were observed. As for the hands and wrists (Figure 14c), no metal nails or pins were found, and the low radiopacity of the pictorial layer allowed us to confirm the absence of junction systems. The RX investigation highlights that the arms–hands parts are each carved from a single wooden piece attached to the torso at shoulder height. The blood drops on both the hands and the feet (Figure 14b,c) are characterised by the same radiopacity found in the drops on the chest (Figure 13). In general, there is little evidence of xylophagous insect damage and limited lacunae and/or abrasion of the original pictorial layers. In contrast, the wooden element constituting the closure of the hollow part at the back appears more degraded, showing a higher density of holes due to the past attachment of xylophagous insects and unevenness in the wooden thickness involved in RX transmission.

(**a**) (**b**) (**c**)

Figure 14. X-ray images of Christ Crucified from Bisignano: (**a**) the knees and legs; (**b**) the feet–ankles; (**c**) the right arm–hand.

Preliminary observation of sample CB_01 (from flesh tone layer) under a digital optical microscope (Figure 15) revealed the presence of a white preparatory layer on which a pinkish-coloured pictorial layer, characterised by a darker pink thin film, has been overlapped. Laterally on the fragment, fabric fibres were observed that could be traced to the use of a canvas, applied in some areas of the sculptures, confirming the evidence observed through X-ray images at high magnification.

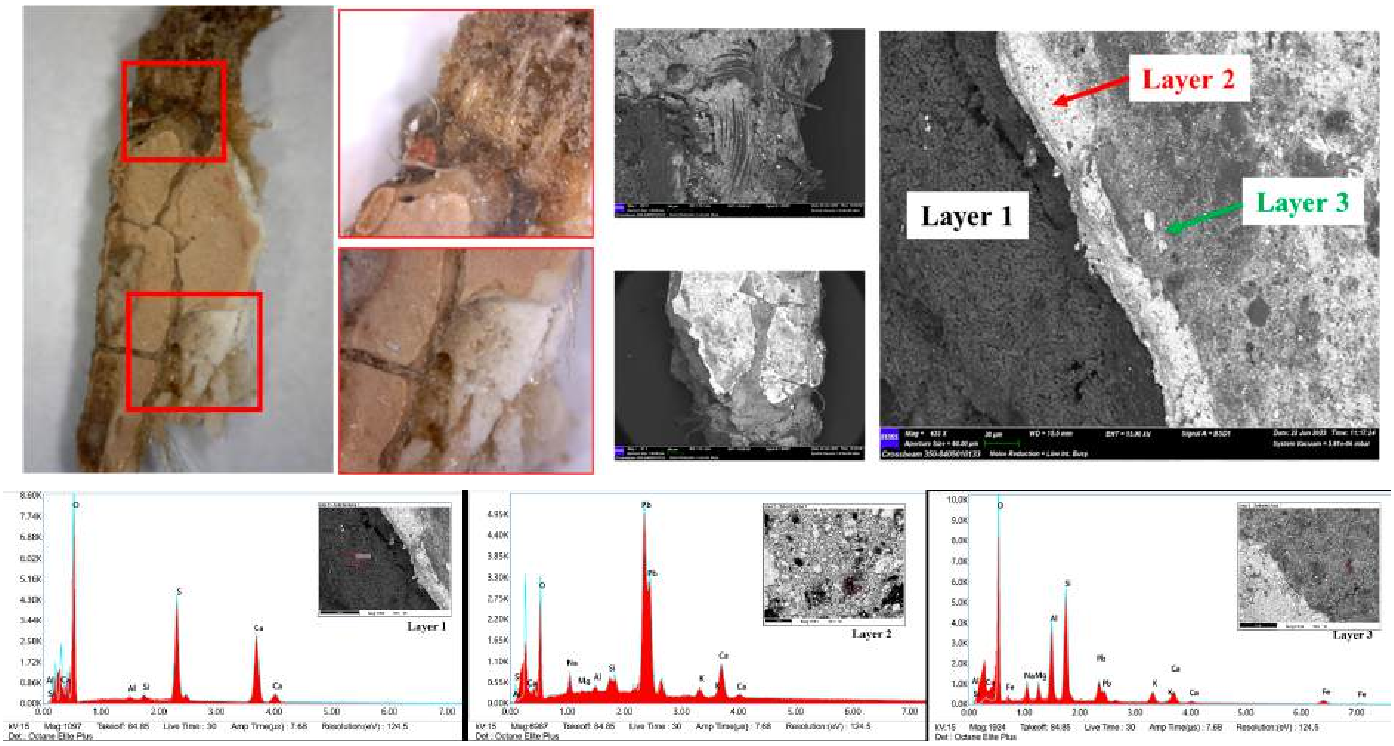


Figure 15. SEM analyses and digital light microscope observations of samples CB_01. EDX spectra obtained from each layer: preparation (Layer 1); flesh tone pictorial layer (Layer 2); darker pink thin film (Layer 3).

The described stratigraphy and the presence of canvas filaments were also documented through SEM image and EDS analyses (Figure 16). The EDS spectra acquired on each three layers document the following stratigraphic sequence, from the bottom: a preparation layer (layer 1), consisting of calcium and sulphur (calcium sulphate) [24,29,31]; a middle layer (layer 2), predominantly composed by Pb, attributable to lead white (lead carbonate, $(PbCO_3)_2 \cdot Pb(OH)_2$) [26]; and a surface layer (layer 3), applied to make the pinkish layering tone, consisting of iron oxide pigments, clay minerals, and probably red lacquer, suggested by the presence of potassium (a chemical element that could be related to the mordant for the red lake) [12,31,32].

Preliminary observations by using a digital optical microscope and SEM of CB_02 sample document that the micro-fragment (from a drop of blood in the ribcage) consists of a homogenous matrix (Figure 16). In particular, the SEM image reveals the presence of radiopaque grains of pigment, and the EDS spectra acquired on these irregular grains detected mercury and sulphur, attributable to the use of cinnabar/vermilion [33,34] and aluminium and sulphur, which can be correlated to a possible use of a mordant in the production of red lake [35,36]. These chromophores (cinnabar/vermilion and red lake) are immersed in an organic matrix that was probably used to three-dimensionally mould the blood drops [37,38].

The xylotomic investigation for identifying the wood species [39] was performed on sample BC_03, from the hair corresponding to a lacuna). The optical microscope observation was carried out in three cross sections: transverse, tangential longitudinal, and radial longitudinal (Figure 17).

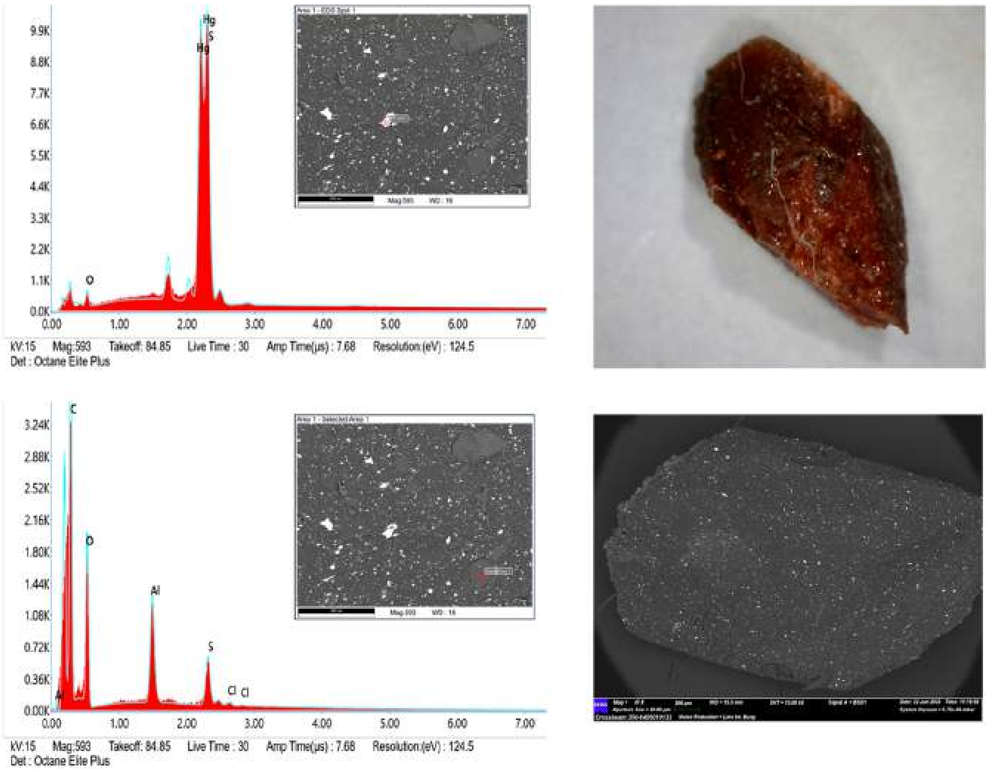
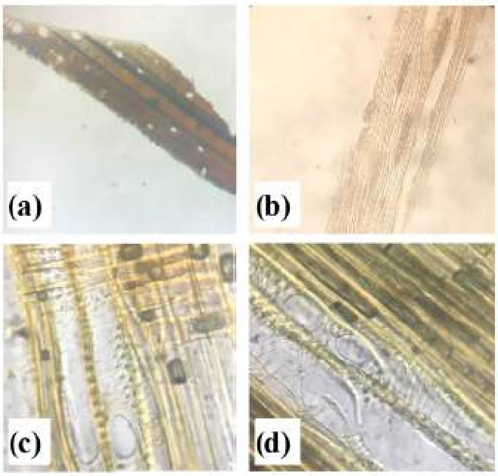


Figure 16. Digital optical microscope observations and SEM images of samples CB_02. EDX spectra obtained on radiopaque pigment and radiolucent dyes grains, added in the organic matrix.



Sample CB_03	Wood of *Acer sp.*
Transverse section	Incomplete ring of diffuse porous hardwood with widely spaced round solitary vessels or in radial rows of 2-4 elements
Tangential section	Homogeneous parenchyma rays 1-4 cell axes wide
Radial section	Homogeneous radii, simple vessel perforation and vessels with spiral thickening

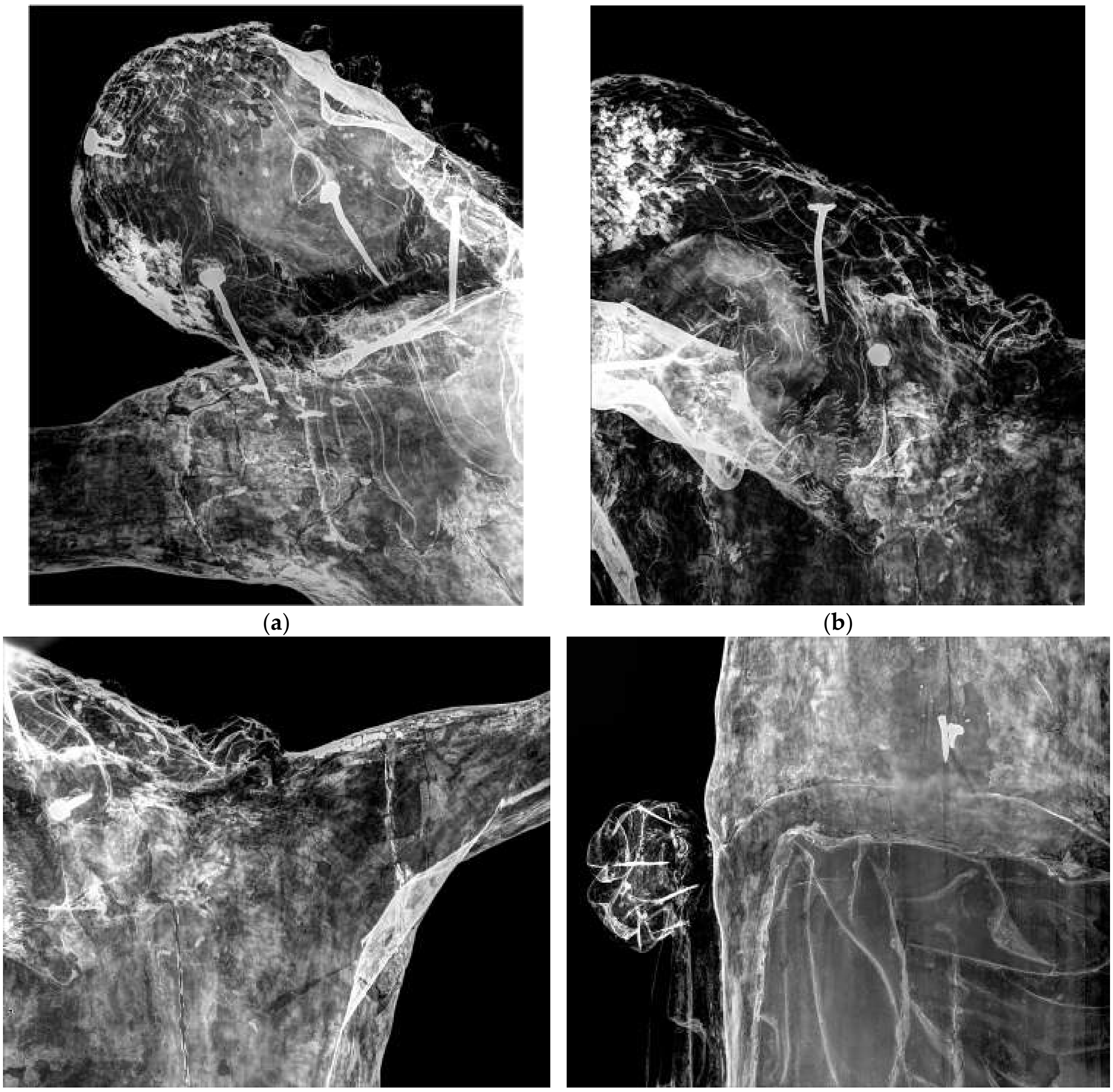
Figure 17. Light microscope images of three cross sections obtained from sample CB_03 and characteristic of the identified wood genus: (**a**) transverse; (**b**) tangential; (**c**,**d**) radial sections. Dimension of observed area is 50 µm.

Schweingruber's keys [40,41] were used for identification: based on the observed typical feature set, the sample is attributable to maple wood (*Acer* sp.), a genus represented by several species that are difficult to distinguish microscopically, especially in the case of small fragments. Maple is a suitable wood for carving, although its use in ancient wooden sculpture is poorly documented [42,43].

3.3. Crucified Christ from the Church of San Salvatore from Gangi (Palermo)

The preliminary inspection by cover meter indicated the presence of metallic nails or pins in the right knee, loincloth knot, head, lower part/neck, and abdomen. Radiographic investigations aimed at understanding the construction technique had limitations due to the high radiopacity of the pictorial materials or the overlapping of more pictorial layers that homogeneously covered the entire wooden surface.

Despite this restraint, information on the interconnection systems between the different carved wooden portions was deduced. The RX projections performed for the head and right shoulder (Figure 18a,b) showed how the anchorage of the head to the main trunk was made by three long nails documented at the base of the nape (Figure 18a,b). A more radiopaque straight line at the base of the head is observed on radiography. The areas of high radiopacity present on the upper portion of the head, particularly along the right side, can be interpreted as fillings (Figure 18c).



(**a**) (**b**)

(**c**) (**d**)

Figure 18. X-ray images of Christ Crucified from Gangi: (**a**,**b**) head and part of the right shoulder; (**c**) neck and left shoulder; (**d**) loincloth.

At the level of the shoulders (Figure 18c), no metallic elements are found. The high radiopacity of the surface pictorial layers does not allow one to clearly observe the wooden volume, but the pattern of the surface cracks in the pictorial surface allowed us to hypothesise a mortise–tenons system, fixed by means of dowels (or pins), for the junctions of the arms to the main trunk. There is a longitudinal–radial shrinkage crack, running from the neck to the navel, that confirms the use of a single trunk to carve the body of the Christ, excluding the head and arms.

The lower part of the torso is not directly visible due to the high radiopacity of the pictorial layer. Instead, the thin surface fracture lines (Figure 18d) affect the pictorial layers and, finally, the lacunae in the underlying pictorial layer and allow documentation of the past conservation state of the sculpture. It seems highly probable that the longitudinal crack at the level of the navel (Figure 18d) was already present in the past and partially reinforced with the two small nails.

In correspondence with the loincloth, a greater radiolucency can be observed (Figure 18d) due to the absence of the lead white pictorial layer. In this portion, thanks to the low radiopacity, the good state of preservation of the wooden support and the absence of degradation attributable to xylophagous insects were confirmed.

The different response in X-ray of the right side of the loincloth and the high number of nails observed at the knot, (Figure 18d), which do not coincide with the other cases, confirms that this portion was affected by the remaking of the entire wooden volume and not only by a superficial pictorial integration. The two small aligned metal elements revealed in the right knee (Figure 19a) are interpreted as anchoring pins for the dowel that was used for the volume construction. The radiographic investigation of the feet and ankles (Figure 19b) verified the absence of metal nails or pins, and the high radiopacity of the pictorial layer (whose lacunae and fractures are well-followed) does not allow us to visualise the perimeter of the junction system used for the attachment of the feet to the legs. Similar observations were carried out for the hands and wrists of this Christ (Figure 19c); only a thin metal wire used to anchor the fragment of a finger can be observed. It worth noting that the thick drops of blood appear radiopaque, deducing that cinnabar or lead-based mixtures were not added to the organic matrix, as revealed in the Cutro and the Bisignano Crucifixes.

(**a**) (**b**) (**c**)

Figure 19. X-ray images of Christ Crucified from Bisignano: (**a**) the knees and legs; (**b**) the feet–ankles; (**c**) the left arm–hand.

For an immediate and preliminary inspection of the pictorial surface and subsequent assessment of the areas affected by retouching or pictorial integration, an observation of the entire artwork was carried out under 365 nm UV LED. This investigation was also fundamental for assessing the areas to be investigated under X-ray fluorescence to study the historical pictorial layers overlapped over time. Observation under UV light provided an initial mapping and differentiation of the protective or consolidating materials applied to the surfaces (Figure 20).

Figure 20. Visible fluorescence under UV LED observation of the pictorial surfaces of Christ Crucified of Gangi, before the restoration works.

On the right side of the body and on the lateral portion of the loincloth, the inhomogeneity of the visible fluorescence behaviour can be attributed to residues of the previous aged protective varnish that had not been completely removed [18,19]. The gilding layers of loincloth with floral decoration showed no evidence of repainting, but the unevenness found is due to the presence of an unevenly applied protective coating that can be localised by its bluish fluorescence response [20]. In some areas, a yellow–orange fluorescence indicating the presence of an organic material (probably shellac) [17], which appears more unevenly on the face and torso of Christ, was observed.

Discontinuity in the superficial pictorial layer was more clearly identified due to the different response under UV LED of the darker underlying layer of the flesh tone [21]. The beard was also affected by repainting; in fact, a darker colouring was observed along the edge that was not affected by the older layer of varnish, distinguishable by the yellowish fluorescence [22]. On the back, in particular, the absence of fluorescence of the repainting is evident, which highlights the path of the fractures generated at the joints in the shoulders and the longitudinal crack of the central part of the torso (also observed in X-ray) [18].

Finally, four surface areas were analysed by an X-ray fluorescence spectrometer to identify the pictorial layers' composition. The chemical analysis aimed to preliminarily qualitatively characterise the complex superimposition of the pictorial layers applied over time, observed by means of a digital optical microscope in correspondence with falls or lacunas of upper layers (Figure 21).

Above the preparation, at least three layers were identified (Figure 21): (1) the first constitutes a probable imprimitura; (2,3) the other two layers are related to layers of flesh tone juxtaposed over time to adapt to the artistic and cultural style typical of *Fra' Umile* (repainting, dated back to 1656) and to compensate for extensive colour losses in the first layer, as revealed by the RX images. The XRF analyses performed on the three selected areas in correspondence with the pictorial layers identified the presence of historically used pigments and excluded the presence of modern synthetic pigments.

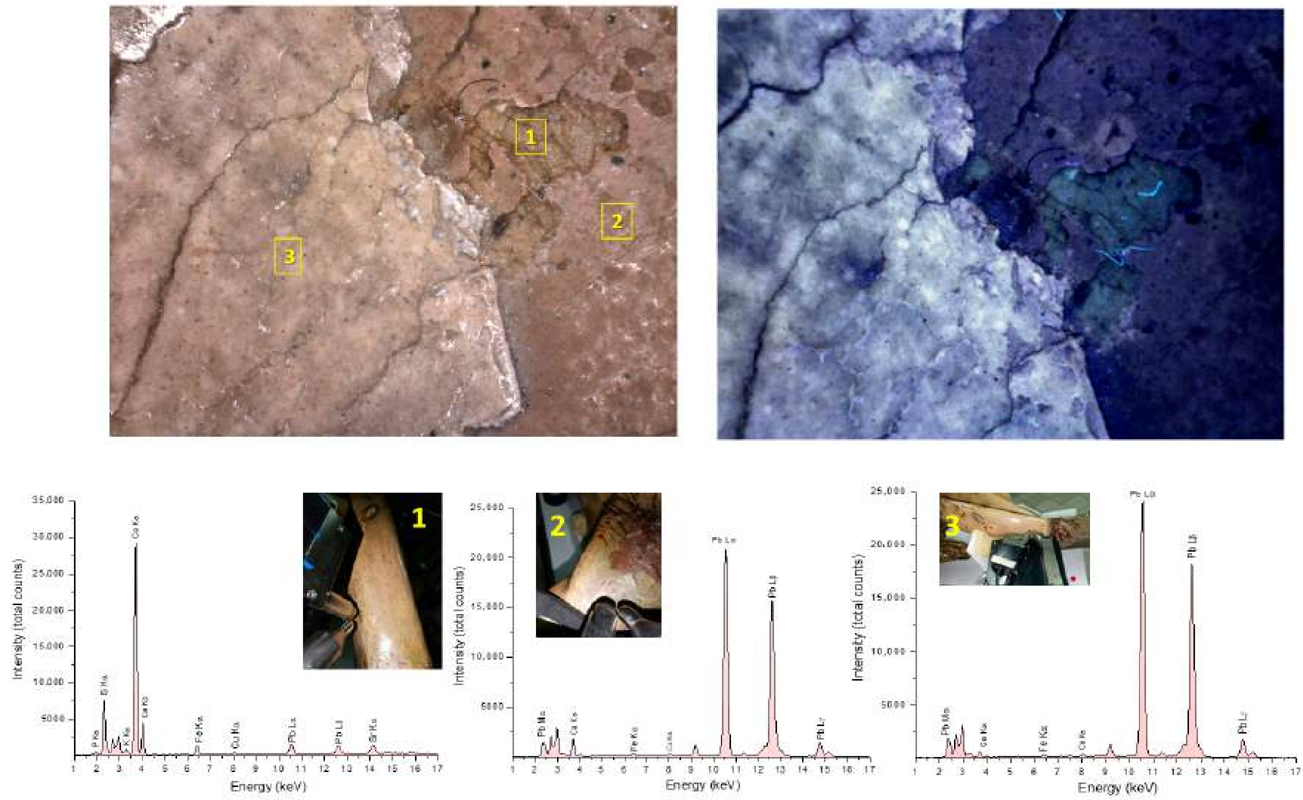


Figure 21. Vis and UV optical microscopic details of the performed XRF analysis with corresponding XRF spectra of the identified layers and pigments, from left: 1, preparation/imprimitura; 2. original pictorial layer; 3. historical repainting layer (1656).

Lead white and iron oxide pigments (ochres or earths) have been identified both in the underlying layers and in the more superficial pictorial layers. In the red layer of the oldest pictorial layer, localised at a lacuna of the surface layer of the foot, the use of lead white and ochres or earths and a low amount of cinnabar/vermilion were identified (Figure 22). In this case, the xylotomic investigation was not carried out, as no samples were authorised.

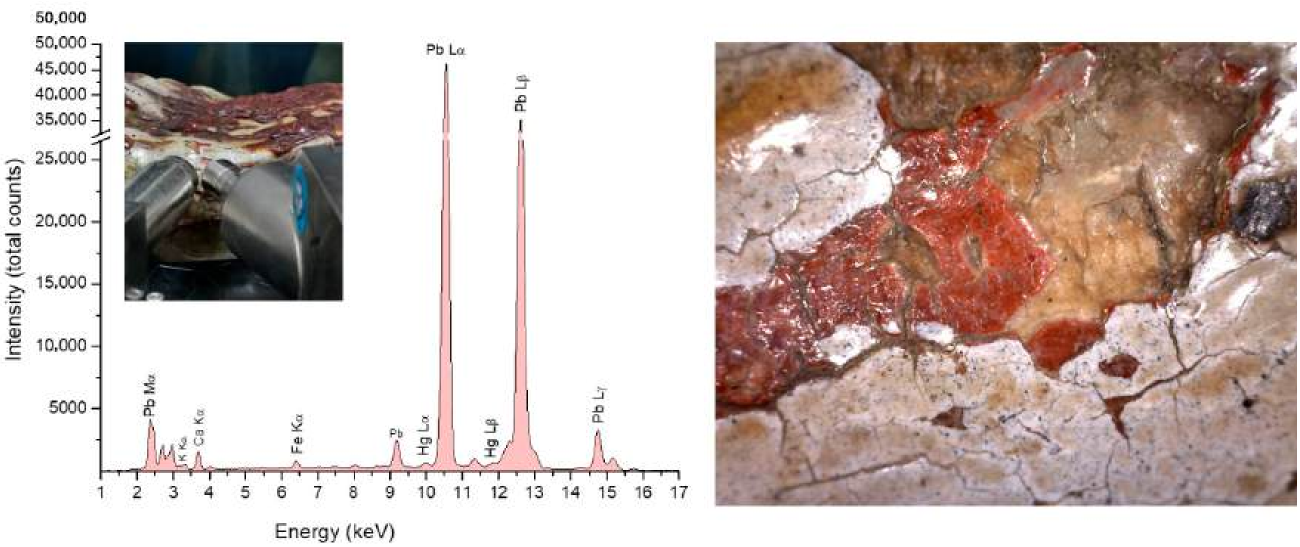


Figure 22. Red pigments localised on the oldest pictorial layer, for which the use of red lead-based pigment has been suggested by high XRF signal intensity of lead.

4. Discussion

All three Crucifix sculptures have been involved in a systematic RX diagnostic imaging investigation. Although the artworks are similar, some technical and conservative differences have been clearly documented. Firstly, with regard to the presence of metal elements, the Christ Crucified in Cutro and the one in Bisignano show a concentration of metallic elements mainly between the head and neck. In the Crucifix in Gangi, in addition to the presence of metal elements such as nails between the head and neck, metal elements were also observed on the right knee, abdomen, and loincloth knot, the latter applied during a previous restoration. From the point of view of the characteristics revealed by the X-ray images, distinctive details emerge in each sculpture. In the Crucifix from Cutro, for example, one can clearly see the nails used to fix the head to the bust and small nails used to fasten the crown of thorns; in addition, the anchoring of the arms was carried out without metal joints but with a tenons–mortise system and pins. The entire sculpture, with the exception of the head and arms, was carved by using a single wooden trunk. These construction characteristics can also be found in the Crucifix in Bisignano. In both cases, Cutro and Bisignano, the rectangular cavity present in the central part of the torso along the entire length was revealed. This evidence agrees with what is reported in the literature [4–6]. Most of the statues, indeed, are made of a single stem, excavated on the back of the statue in order to prevent the opening of the shrinkage cracks, and all the components of the figure that cannot be included on the projection of the stem are carved on external wooden parts, jointed with mechanical connections, strengthened by organic glue.

The presence of a canvas (an incamottatura to reduce the movement of the wood along the joints) along the left arm of Crucifix in Bisignano, constitutes a different technical choice from that of Cutro.

In the Crucifix in Gangi, radiographic investigations aimed at understanding the construction technique showed limitations due to the high radiopacity of the double lead-based pictorial layers covering the entire wooden surface. However, some distinctive details emerged, such as the radiopaque stucco integration on the head, face, and loincloth, indicating probable restorations over time after its creation.

For this Crucifix, the anchoring system of the arms via the tenon–mortise system and of the reclining head carved separately and fixed to the trunk via nails remain the same as the two previous cases. However, the rectangular cavity in the trunk was not revealed in the Gangi Crucifix, and the absence of this technical solution in fact caused the formation of shrinkage fractures, highlighted on the x-ray images.

From a conservation point of view, all three artworks show a good general conservation state, with little evidence of xylophagous insect damage and limited lacunae or abrasions of the pictorial layers. Thanks to the wooden samples analyses, in two cases, it was possible to identify the type of wood used in the production of the sculpture or part of this. For the Cutro Crucifix, the use of poplar (*Populus*) was identified by morphological SEM images, while for the Bisignano Crucifix, the use of maple wood (*Acer* sp.) was identified by cross-sectional optical microscope observation. The former appears more commonly used than the latter in the 16th and 17th century wood sculpture production. It should be noted that the identification of the wood species relates to the head of the crucifixes investigated; the impossibility of systematic sampling does not allow for a complete identification of any different genus used for carving the arms and the main trunk.

In the case of Bisignano, however, it was hypothesised, on the basis of the continuous trend and the same density of the fibres observed in RX, that the head was obtained from part of the same trunk.

In order to fully understand the differences and similarities of the painting techniques used in the three crucifixes, SEM-EDS investigation and X-ray fluorescence analyses, where sampling was not permitted, were carried out. The SEM-EDS analyses performed on the Cutro Crucifix allowed us to identify the use of traditional historical pigments, such as lead white, cinnabar/vermilion, and minium or litharge. These pigments were found in the flesh tones and blood drippings. Similarly, analyses carried out on the Crucified Christ in Bisignano confirmed the use of these pigments, and iron oxide pigments have also been hypothesised [31,44]. Both crucifixes show a similar stratigraphic sequence, with a preparation layer consisting of calcium sulphate (gypsum) [29]. Analyses carried out on the Crucified Christ in Gangi by X-ray fluorescence investigation also revealed the following pigments: lead white and iron oxide pigments were identified for the flesh tone layers. For all three artworks, the use of cinnabar/vermilion mixed with minium or litharge with red lake in the organic matrix appears likely in the blood areas [17]. Table 1 shows the main identified chemical elements found in the three works with the identification hypothesis of the preparation layer and the probable pigments used for the embodiment and blood drops.

Table 1. Main results obtained through elemental analysis on the three crucifixes analysed.

Artwork	Sample	Colour	Identified Elements	Preparation Layer	Identified Pigments
Crucified Christ from Santissimo Crocifisso Church at Cutro (Calabria)	CC_01	Flesh tone	Ca, S, Hg, Si	Calcium sulphate	cinnabar/vermilion
	CC_02	Flesh tone	Ca, S, Pb, Hg, Si, Al	Calcium sulphate and lead white	cinnabar/vermilion; earth; lead white; litharge
	CC_03	Blood Dark red	Ca, S, Pb, Hg, P, Si, Al, Mg, K	Calcium sulphate	cinnabar/vermilion, earth; lead white; minium; shellac; litharge
Crucified Christ from Sanctuary of *Sant'Umile da Bisignano* (Calabria)	CB_01	Flesh tone	Ca, S, Pb, Si, Al, K, Mg, Fe	Calcium sulphate and lead white	cinnabar/vermilion; earth; lead white; minium; shellac; litharge; pigment
	CB_02	Blood Dark red	Hg, S; Al, Cl		cinnabar/vermilion; shellac
Crucified Christ from Saint Salvatore Church at Gangi (Sicily)	3 points	Flesh tone	Pb, Fe, Ca	Calcium sulphate	lead white; ochre or earth pigments
	1 point	Blood Dark red	Pb, S, Hg, Fe, Ca	-	red lead; low amount of cinnabar/vermilion; ochre or earth pigments

The similarities observed both in the polychrome (Table 1) and construction technique of the wooden sculptures reflect an artistic and historical tradition typical of artworks created in the period between the 16th and 17th centuries. Moreover, the observed similarities support the attribution to the same artist or workshop. In fact, although some small differences have been observed between the Calabrian works, whose attribution is known, and the Sicilian one, whose attribution is uncertain, we can affirm that they are similar in terms of the construction technique in terms of the number of pieces and the assembly methods of the wooden statue and the composition and stratigraphy of the pictorial layers

5. Conclusions

The three wooden sculptures analysed, the Crucified Christ from *Santissimo Crocifisso* Church at Cutro (Calabria), the Crucified Christ from the Sanctuary of *Sant'Umile da Bisignano* (Calabria), and the Crucified Christ from Saint Salvatore Church at Gangi (Sicilia), revealed interesting similarities thanks to the analyses conducted using a digital direct radiography imaging, SEM-EDX, and X-ray fluorescence analyses. The investigations showed similar construction techniques and pictorial materials for the three sculptures, supporting the hypothesis of a chronological coincidence and attribution to the same workshop based on stylistic analyses and historical archival documents. The similarities in construction and artistic techniques reflect an artistic tradition of the 16th and 17th centuries. These observations support the attribution of the artworks to *Fra' Umile da Petralia*, and regarding that of Gangi, to his workshop and successors relating to the pictorial materials and artistic technique used for the stylistic adaptation entrusted to *Fra Umile's* successors testified to in an archive document from 1656.

This preliminary study highlights the importance of systematic research into the materials and construction solutions of wooden crucifixes in Southern Italy, not yet widely available to the scientific community, which could contribute to the correct identification and differentiation of the active artists and their workshops. Starting from the study of works of art of certain attribution, as in this case, the systematic collection of technical knowledge on the pictorial technique, the carving and construction techniques, the assembling, the woods selected for the different parts of the statue, and those used in the different geographical areas, would enable a set of knowledge and data to support attributions even on scientific bases and not only on artistic–stylistic criteria often influenced by the difficult reading of the original models and surfaces altered by numerous overlaps and restorations.

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